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Positional Variability Associated with the Wear of the Ballistic-Laser Protective Spectacles (B-LPS)

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and
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Division of Ocular Hazards Research

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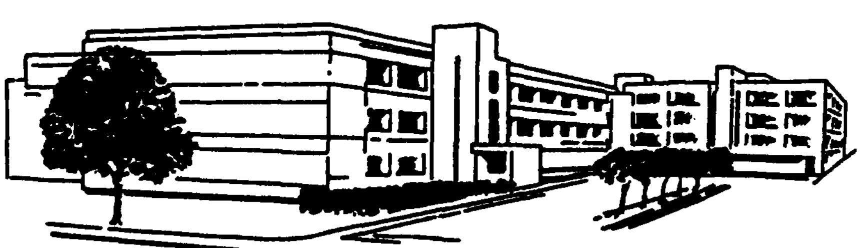

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Human Subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 50-25 on the use of volunteers in research.

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The Ballistic-Laser Protective Spectacles (B-LPS) have been developed and fielded to afford soldiers ocular protection against ballistic and laser threats in training and wartime environments. The "one-size-fits-all" approach assumes that the location and orientation of the spectacles relative to the eyes of the wearer fall within a "tolerance" range. In this study, photographs of 67 active duty soldiers were analyzed by a computerized method to characterize to what extent the spectacles are worn in accordance with design criteria. Translational variability along three axes and rotational variability around two axes were measured. For most estimated parameters, the B-LPS were worn almost exactly according to design. However, the spectacles were found to rest approximately 8 millimeters further from the anterior aspect of the eye than intended. In addition, a significant degree of unexpected rotation (Mean-13.4 degree) (continued)

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Abstract

The Ballistic-Laser Protective Spectacles (B-LPS) have been developed and fielded to afford soldiers ocular protection against ballistic and laser threats in training and wartime environments. The "one-size-fits-all" approach assumes that the location and orientation of the spectacles relative to the eyes of the wearer fall within a "tolerance" range. In this study, photographs of 67 active duty soldiers wearing the B-LPS were analyzed by a computerized method to characterize to what extent the spectacles are worn in accordance with design criteria. Translational variability along three axes and rotational variability around two axes were measured. For most estimated parameters, the B-LPS were worn almost exactly according to design. However, the spectacles were found to rest approximately 8 millimeters further from the anterior aspect of the eye than intended. In addition, a significant degree of unexpected rotation (Mean - 13.4 degrees) was found around one of the two axes. These findings suggest a need to assess the impact of wearer variability on spectacle performance and to ensure that spectacles are properly fitted when issued.

Positional Variability Associated with the Wear of the Ballistic-Laser Protective Spectacles (B-LPS)

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Introduction

The possibility of ocular injury due to on-axis exposure to a laser source is increasing in today's Army. Potential exposure may result from accidents involving currently fielded "friendly" systems (e.g., rangefinders or target designators) or from threat lasers in situations ranging from isolated surveillance encounters to full-scale conflict. In response to this potential source of injury, the Ballistic-Laser Protective Spectacles (B-LPS) have been developed and fielded to afford soldiers a measure of protection against untoward exposure. Current technological and logistical constraints have resulted in the production of a "one-size-fits-all" product. Design criteria of the B-LPS include assumptions that the location (translational variability) and orientation (rotational variability) of the lenses of the spectacles relative to the eyes of the wearer will fall within a "tolerance" range. Considering the recognized heterogeneity of facial features, the center of the eye for a particular wearer is likely to vary from the design center of the spectacles along any of three axes and/or the B-LPS may be rotated around any of these same axes. This variation may possibly affect the level of protection provided by the spectacles and may have an impact on the introduction of alternate technologies in the future. In one quarterly report (1) by the contractor currently producing the B-LPS, the importance of assessing the impact of this variability was noted, although to date no such assessment has been made. This study was undertaken to measure and describe the translational and rotational variability of the B-LPS in a group of active duty soldiers. The methods for this assessment were created *de novo* utilizing available resources; thus, results reported herein include an assessment of the limitations of these methods.

Methods

In January of 1989, 150 sets of B-LPS were provided to the soldiers of a U.S. Army training battalion with significant potential for inadvertent laser exposure. Soldiers were issued individual sets of spectacles and were instructed on their use and wear. After a period of approximately ninety (90) days, we visited this unit to administer questionnaires and photograph all current wearers of the B-LPS.

Details concerning the content, administration, and analysis of the questionnaires are contained in a separate report (2). Questionnaires were completed by all subjects immediately prior to or after the photographic session described below. Information collected on questionnaires was reviewed immediately and subjects were interviewed to clarify any incomplete or unclear details. Information collected through the questionnaire and included in the analyses of this report include the following six fields: rank (officer versus enlisted), degree of B-LPS use (heavy versus light), whether the subject wore glasses, whether the subject used the nose pads provided with the B-LPS, whether the subject used the spectacle-restraining band, and whether the subject reported any problems with helmet--B-LPS interaction.

Photographs were taken of all subjects to determine the relative location of each eye with respect to B-LPS. All photographs were taken by a single medical photographer with training and experience in anatomical photography. Using a

Hasselblad camera with an 80 millimeter lens and a 21 millimeter extension ring located between the body and lens, two photographs (one frontal view and one left-lateral view) were taken of each subject wearing the clear B-LPS. Photographs were available for immediate review in a 2.25 x 2.25 inch format. In some cases, if the subject did not bring his clear B-LPS, photographs were taken with the subject wearing the sunglass B-LPS. The clear and sunglass B-LPS are structurally identical, varying only in the addition of a sunglass tint within the polycarbonate matrix of the sunglass version.

During each photograph session, the camera was held at a height approximately equal to the level of the pupils of the subject. The frontal view photograph was taken approximately 26.6 to 27.9 centimeters from the B-LPS; during this photograph, the subject was instructed to look into the center of the lens. The photograph from the left-lateral view was taken approximately 26.6 to 27.9 centimeters from the subject's left eye, orienting the camera approximately perpendicular to the horizontal line-of-sight of the subject at the point of the left corneal surface. During this photograph, the subject was instructed to look straight ahead (i.e., toward the left in the viewfinder of the camera). A vertical tape was positioned in the background of each lateral photograph to provide an absolute frame of reference for evaluating the rotation of the B-LPS. At the time of photography, the subject's number was written onto each photograph so that pictures could be matched with information collected on questionnaires.

Photographs were analyzed using a Summa Graphics Tablet while viewing through a magnifying lens. Eight points of analysis were prospectively identified on the frontal view: 6 points on the B-LPS (Fig. 1) and the centers of the 2 pupils. On the lateral view 7 points were identified: 4 points on the B-LPS (Fig. 2), the highest and lowest visible points on the vertical tape measure; and the anterior aspect of the left cornea at a height equal to the center of the pupil. Each photograph was mounted on the Summa Graphics Tablet by insertion into an acetate template created for this purpose. Each point for each photograph was identified through the magnifying lens. The points on frontal and lateral photographs were assigned an order so that all points were collected in the same sequence on each photograph. Using a mouse-device with a cross-hair aiming piece, the two-dimensional coordinates for each point were determined and electronically stored in a microcomputer. Each photograph was analyzed twice (i.e., 2 repetitions) by each of 4 raters to create 8 "observations" for each picture. For each rater, all first-repetition photograph analyses were completed before initiating any second repetitions. In a later session, two investigators reanalyzed all frontal view pictures. In this later session, the coordinates for the following six points were determined: the two upper, outer corners of the lenses; the centers of each pupil; and the two pointed tips located at the inferior aspect of the nosepiece of the B-LPS (Fig. 1).

The coordinates for each observation of each frontal view photograph were transformed in the following manner. Within a Cartesian coordinate system (x,y), each point was translated an equal distance along the x- and y-axes so that the point corresponding with the right upper corner of the B-LPS occupied a position of (0,0). All points were then transformed into a polar coordinate system (r,theta) and rotated around the right upper corner (center of the system) so that the line segment defined by the left and right upper corners coincided with the line defined by zero (0) degrees of rotation. All points were then transformed back into a Cartesian coordinate system.

Coordinates for each observation of each lateral view photograph were transformed in the following manner. Within a Cartesian coordinate system (x,y), each point was translated an equal distance along the x- and z-axes so that the point

corresponding with the left upper corner of the B-LPS occupied a position of (0,0). All points were then transformed into polar coordinates (r,theta) and rotated around the left upper corner so that the horizontal components of the high and low points on the vertical tape were equal (i.e., so that the tape was oriented in a vertical position). All points were then transformed back into a Cartesian coordinate system.

The data for each photograph were analyzed for coding errors possibly attributable to errors in technique. The eight observations for each photograph (four investigators with two observations per investigator) were initially evaluated by comparing the location of each point from each observation with the mean location of that point as determined by averaging all observations. Five frontal observations were identified (from a total of 536 observations) in which one or more points were more than half a millimeter from the average location; 2 of these deviations (from 2 different investigators) resulted from collecting points in the inappropriate sequence. In these 2 cases, the malsequenced coordinates were reassigned in the appropriate order. For three photographs (one each from three different investigators), the source of the error could not be identified, and was of such a degree to make the existing data uninterpretable. In these cases, the respective investigators reanalyzed and collected data for the single photograph according to the methods above. Inter- and intra-observer measurement variability were assessed by computing means, standard deviations, and Pearson product-moment correlation coefficients. Inter-observer comparisons were made for each observer using coordinate estimates which were the average of the two repetitions. Subsequent analyses utilized only the average location for each point.

A three-dimensional coordinate system was defined to facilitate estimation of parameters of interest. The x-axis was defined to correspond with horizontal deviation in the frontal view (positive is toward the subject's left), the y-axis corresponds with vertical deviation in both the frontal and lateral views (positive is up), and the z-axis corresponds with horizontal deviation on the lateral view (positive is to the subject's front). All distances are specified in millimeters. By convention, positive rotational variability of the B-LPS is defined as counter-clockwise rotation when viewed from the positive end of each particular axis. All angles are specified in degrees.

Within this coordinate system, several anthropometric parameters were identified as pertinent in describing the relationship of the eye (either right or left) to the B-LPS (Table I). The first parameter is the two-dimensional (x and y) coordinates of the point at which the line of sight intersects the front aspect of the B-LPS. This is referred to as the Line-of-Sight/Lens Intersection Point (LOSLIP) and is defined specifically when the B-LPS are oriented according to design conditions. The second parameter is the distance between the LOSLIP and the center of the eye (COE). A third anthropometric parameter is the rotation of the B-LPS around the x-axis. The vertical tape visible in the lateral photograph was used as a reference standard. The fourth parameter is the rotation of the B-LPS as seen in the frontal view (i.e., around the z-axis). The line containing the pupil centers served as a horizontal reference. The fifth parameter is the angle defined by the line-of-sight and the plane tangent to the front surface of the lens at the LOSLIP, referred to as the Line-of-Sight/Lens Angle (LOSLANG). The (0,0,0) point in the system described above corresponds to the midpoint of the line segment connecting the design right and left LOSLIP's. Design locations of various points on the surface of the B-LPS were determined using drawings and specifications contained in the Technical Data Package for the B-LPS. According to these specifications, the design location of the left LOSLIP is (32, 0, 0). Similarly, the left-upper corner of the B-LPS is located at the point (74, 19.3, -34.2).

We determined the above-enumerated parameters as follows: Rotation around the z-axis and x-axis was measured from the frontal and lateral view photographs, respectively. The two-dimensional (x- and y-) coordinates of the LOSLIP were determined for each eye. Then, accounting for rotational effects, a coordinate system was established in which the LOSLIP and COE defined a line parallel to the z-axis (i.e., both points had identical x- and y-coordinates). In this system, the LOSLIP-COE distance was measured. Finally the LOSLANG was estimated.

The x-component of the LOSLIP and COE for each subject was assessed in the frontal photograph. The distance between the upper, outer corners of the B-LPS was felt to be a reliable standard for calculating distances along the x-axis so all measures of x-deviation from the center point use this distance as a reference standard. The center of the pupil was used a a first approximation for estimating the x-component of the COE. Final estimates of the observed x-value of the LOSLIP and the COE include calculations to correct for the following effects: 1.) due to the relatively close location of the camera to the subject, the effect of parallax results in estimated y-values that are larger than actual values and 2.) due to focussing on a near target, the observed position of the pupil is somewhat medial to the location that would be observed if the subject were focussing on a distant target.

Rotation around the x-axis confounds attempts to estimate the y-component of the LOSLIP from frontal view photographs. Two methods were devised to adjust for this effect. The first (Method 1) was a proportional scaling method utilizing vertical distance relationships available strictly in the frontal view photograph. Observed shortening of the vertical component of the line segment connecting either upper, outer corner of the B-LPS with its respective nosepiece tip was used as a scale for predicting the actual y-value of the LOSLIP from the observed value. The second method of correction (Method 2) used rotational information available on the lateral view photograph to adjust for the observed y-value of the LOSLIP. Based upon the estimate of rotation, the observed y-component of the left LOSLIP can be trigonometrically adjusted to determine its value in the design coordinate system.

Estimates of the z-component for each left LOSLIP and left COE were made from the lateral photograph of each subject. Because of the curvature of the lens, it is impossible to determine the exact location of the LOSLIP directly; therefore, two methods were devised to estimate its actual location. The first (Method 1) used the upper-left corner of the B-LPS as a reference point. The z-component of the LOSLIP can be roughly estimated using observed rotation around the x-axis. This method assumes no variation of the LOSLIP along the x- and y-axes. In the second method (Method 2), the upper-left corner of the B-LPS again served as a reference point, but calculations were based upon rotational information, the x- and y-values of the LOSLIP as measured on the frontal view, and knowledge of the toroidal structure of the B-LPS. This latter method is mathematically complex, but felt to be more reliable than the former. The y-values used in z-component calculations correspond to those derived from Method 2 described in the previous paragraph. Estimates of the z-component of the left COE for each subject were calculated from lateral photographs. These estimates used the left, upper corner of the B-LPS as a reference point and assumed that the front surface of the cornea is located 13.25 millimeters anterior to the rotational center of the eye. Z-axis results are presented as the distance (millimeters) of the left COE from the left LOSLIP.

Based upon the estimated three-dimensional coordinates of the LOSLIP, the three-dimensional coordinates of the COE, and the known toroidal structure of the

B-LPS, the LOSLANG was calculated for each subject. In LOSLANG calculations, estimates of the z-component of the LOSLIP derive from the second method described above.

Correlations reported are Pearson product-moment correlation coefficients. Comparisons between mean values were made using a two-tailed paired t-test. For subgroup analyses in which more than 2 groups are represented in a particular category, statistical comparisons were made using a one-way ANOVA.

Results

We obtained 67 sets of paired photographs of members of the training battalion. Questionnaires were also completed for each of these subjects. Analyses of intra-observer variability demonstrated a high degree of consistency across repetitions by observers. Selected examples are displayed in Table II. Coordinate "2x" corresponds to the x-coordinate of the left, upper corner of the B-LPS in the frontal view photograph. The small standard deviations indicate that across subjects, the estimates varied by only a few millimeters on the photographs; nonetheless, the high correlation coefficients (all > .95) indicate that raters were able to measure this variation consistently. In contrast, for point "3y", which was one of the four nosepiece corners analyzed in the first session of the frontal view photographs, the across-repetition correlations for each rater were somewhat diminished. This may have been due to the extremely small variability across subjects (SD < 1 mm for all repetitions) which may have been more difficult for raters to distinguish consistently, but may also have been due to an actual difficulty in identifying the point on the photograph. Subjective comments by the raters substantiate the latter possibility. The x- and y-coordinates of point 7 correspond to the location of the left pupil in the frontal photograph. Correlation coefficients again demonstrate a high consistency of raters to determine relative locations precisely, even though the task of identifying the center of the pupil requires some subjective interpolation.

Measures of inter-observer variability also demonstrate that the technique of coordinate determination was reproducible across raters. As seen in Table III, correlation coefficients are consistently in excess of .90. The correlations for the nosepiece coordinate ("3y") are somewhat smaller than those for other coordinates.

The two methods of y-coordinate estimation for the LOSLIP are compared in Figure 3. For both eyes, the agreement between the two methods is excellent with a correlation coefficient of .919. For subsequent analyses, y-coordinate estimates are based upon the second method.

The two-dimensional coordinates (x and y) of the LOSLIP for each eye of each subject are graphically displayed in Figure 4. The mean locations are very near the right and left design locations of (-32,0) and (32,0), respectively. The right LOSLIP is estimated to be 1.2 millimeters closer to the nose (p = .0001) than the left LOSLIP. Along each coordinate axis, all estimates are within approximately 5 millimeters of the mean. The radii of circles which contain 95%, 75% and 50% of the observed LOSLIPs were calculated to be 2.5, 3.6, and 4.9 millimeters for the right eye and 2.2, 3.6, and 5.3 millimeters for the left eye, respectively. The location of the LOSLIPs on the B-LPS is shown in Figure 5.

The two methods of z-coordinate estimation are compared in Figure 6. The distance between the left LOSLIP and the left COE is displayed in millimeters. There is excellent agreement between the two methods of estimation, with a correlation coefficient of .854. The mean estimate of the distance between the LOSLIP and the COE by Method 1 is 37.1 millimeters; by Method 2 the mean is 40.4 millimeters. The 3.3 millimeter difference between the two estimates is statistically significant ($p < .0001$). Both results are significantly different from the design criteria distance of 32.25 millimeters (2 millimeters of lens thickness +17 millimeters from lens to cornea and 13.25 millimeters from cornea to COE). In Figure 7, plots are shown of the LOSLIP-COE distance in the x-z and y-z planes. These emphasize that in comparison to variability along the x- and y-axes, the variability of the COE along the z-axis is over twice as large. The data displayed in Figure 7 was calculated so that the x- and y-components of the LOSLIP and COE are coincidental (i.e., the line-of-sight is parallel to the z-axis).

Rotation of the B-LPS around the z-axis was minimal. The mean estimate for all subjects was approximately 3 minutes of arc (Table IV). In contrast, significant rotation around the x-axis was detected. The mean rotation as seen on the lateral view was 13.4 degrees. The B-LPS of all subjects were rotated to some degree in the positive direction, ranging from 1.7 to 26.7 degrees. Similarly, the estimated LOSLANG was significantly less than according to design. The mean was 69.6 degrees and individual estimates ranged from 58.5 to 76.9 degrees.

Relationships between the LOSLIP-COE distance, the LOSLANG, and rotation around the x-axis are displayed graphically in Figure 8. The high coefficient of determination ($R^2 = .693$) in Figure 8b suggests that much of the variability observed in the LOSLANG is due to the significant degree of rotation around the x-axis. The intercept of the fitted straight line agrees closely with the predicted LOSLANG.

Summary information on mean estimates of parameters by selected subgroups is presented in Table V. For most subgroups, the estimates are nearly identical. Thus, as expected, there is no significant difference among any of the measures for those who normally wear glasses versus those who do not. Excluding comparisons in which one group consists of "No response", the only subgroup/parameter combination in which mean estimates were significantly different from one another ($p<.05$) was the comparison of the LOSLIP-COE distance among wearers of the nose pads versus those who did not ($p=.009$).

Discussion

The results of this study indicate that the use of the graphics tablet as a method of estimating anthropometric aspects of B-LPS wear is precise. The high degree of consistency of measurements within and between raters demonstrates that the technique was sensitive to the amount of variation present in the sampled population. Thus, we do not feel that the relatively small size of the pictures negatively affected our ability to make accurate measurements. Reported subjective difficulty in clearly identifying certain points on the photographs (i.e., the corners of the nosepiece) was associated with a moderate reduction in consistency, however. A reduction in sensitivity also is expected when the variation in the sample is small and will therefore contribute to reduced consistency. In conducting our analysis, we attempted to identify points on the B-LPS that met two criteria: 1.) maximum spatial separation along the dimension(s) of interest and 2.) containing landmarks that are clearly distinguishable.

The ability to pinpoint landmarks on the nosepiece is confounded by the presence of rounded corners and the overlaying of indistinct images in a translucent matrix. In contrast, the upper-outer corners, lower-outer corners, and inferior tips of the nosepiece maximize the desired criteria. In addition to being precise, we also feel that the method of photographic analysis is valid. We have substantiated our results by taking several approaches to each estimate (most of which are not included in this report), and have observed that the results are internally consistent.

Nonetheless, several limitations in the photographic technique itself (i.e., prior to the computer analysis) are recognized. First, the camera was hand-held, not mounted on a tripod or other fixed platform. While this facilitated the acquisition of high quality photographs, it may have introduced some variation into the relationships and angles observed. For example, the observed difference in the left and right mean LOSLIP x-coordinate estimates may be due to a systematic pattern of holding the camera more toward one eye than the other. The approach taken in the computerized analysis was selected to minimize such effects.

Second, due to the relatively short photographic distance, pupils were in a position of moderate convergence and the effect of parallax resulted in an under-estimation of the absolute x-coordinate of the LOSLIP (and COE). For example, prior to correction for these effects, the initial x-coordinates of the right and left LOSLIP were -30.7 and 32.1 millimeters, respectively. Because we knew the actual focal length and were able to estimate the distance between the eye and the B-LPS surface, we were able to correct the estimate for each subject for both of these effects.

A third aspect of the photographic process which may have introduced error (systematic and/or random) into our estimates was the fact that the two photographs were taken sequentially rather than simultaneously. We attempted to minimize this effect by drawing upon what we felt were the most reliable aspects of each photograph. Thus, we did not feel that y-coordinate estimates for the LOSLIP or COE obtained from the lateral view would be as reliable as those available on the frontal view. Estimates of lateral rotation are considered highly reliable because a vertical reference was included in the lateral view photographs. In particular, we do not feel that the marked deviation of the observed estimate from the expected value (13.4 versus 0 degrees) can be explained by systematic flaws in data acquisition or analytic procedures.

No correction was made in this analysis for the effect of refraction which occurred as the subject looked through the B-LPS lens. Such refraction does not affect the observed LOSLIP location, but may affect the estimated x- and y- coordinates of the COE. The only anthropometric parameter whose estimate could have been affected by such a variation is the LOSLIP-COE distance. Results of analyses not shown indicate that COE variations of a few millimeters along either the x- or y-axis result in correspondingly small (<1mm) changes in the LOSLIP-COE estimate.

The parameter estimates provided by this study suggest that unexpected deviations from design conditions are inherent in the wear of the B-LPS. While the line-of-sight passes through the anterior surface of the lens with little variation from the design location, it appears that the lenses of the B-LPS are approximately one-half inch further from the eyes than expected. This increased LOSLIP-COE stand-off distance means that as the subject shifts his/her line-of-sight away from a horizontal, forward-looking posture, the location on the anterior surface through which the visual axis passes will be significantly further from the LOSLIP than intended. If we consider two B-LPS wearers, one whose fit according to design (Wearer 1) and one whose fit

with an increased stand-off distance (Wearer 2), significant differences in lens-eye relationships are anticipated during the performance of simple tasks. While tracking a target, for example, the line-of-sight would traverse a greater distance along the surface of the B-LPS in Wearer 1 than in Wearer 2. Similarly, instantaneous values of the LOSLANG during this simple tracking task are likely to be quite different. Depending upon the laser-protective technology of the B-LPS, such differences may result in under-protection.

Similarly, the marked degree of rotation around the x-axis affects the performance characteristics of the B-LPS. First, the observed rotation results in a marked reduction in the LOSLANG. Non-coincidence of the design COE and rotational centers of the toroid dictate that the expected LOSLANG will never be ninety (90) degrees. However, protective technologies are likely to rely upon the assumption that the angle is somewhere close to this value. The estimated average of approximately seventy (70) degrees found in this study may be of such significance to invalidate this assumption. Furthermore, given a baseline deviation of such magnitude, shifts of gaze in specific directions are likely to result in angles of incidence which are incompatible with design protective mechanisms. Analysis of such outcomes demands further attention.

Deviations of the "fit" of the B-LPS from design conditions may affect aspects of their performance other than laser protection. During interviews, multiple wearers commented that the spectacles provided minimal protection against the barrage of dust and small rocks which is a routine part of their military duties. An increased lens-eye stand-off distance and a systematic malrotation of the B-LPS may have contributed to such events.

In summary, we feel there is a need for further analysis of the anthropometric relationships associated with the wear of the Ballistic-Laser Protective Spectacles. Studies should be designed to avoid the limitations of our technique as noted above. Confirmation of the findings of this study would suggest a need to consider modification of the construction process for spectacles fielded in the future. Other investigations to assess to what degree, if any, the observed deviations from design affect protection or performance would provide a framework for such considerations. In addition, specific identification of the causes associated with our findings would benefit the design of other, as yet undesigned, ocular systems.

References

1. "Ocular Protection Against Laser Radiation and Ballistic Fragments, Quarterly Report No. 2, August 1986, prepared by American Optical Corporation Technology Division for the U.S. Army Medical Research Acquisition Activity, contract No. DAMD17-86-C-6079, Attachment #2, paragraph 3.5.1. Positional Tolerances, p. 49.

2. Mastroianni G, Gunzenhauser J, Knudson K, Stamper D, and Stuck B. "Field Evaluation of Laser Eye Protection." Letterman Army Institute of Research, 1989; Institute Report (in press).

Figure 1. **Landmarks on the B-LPS Used in Frontal View Analyses**

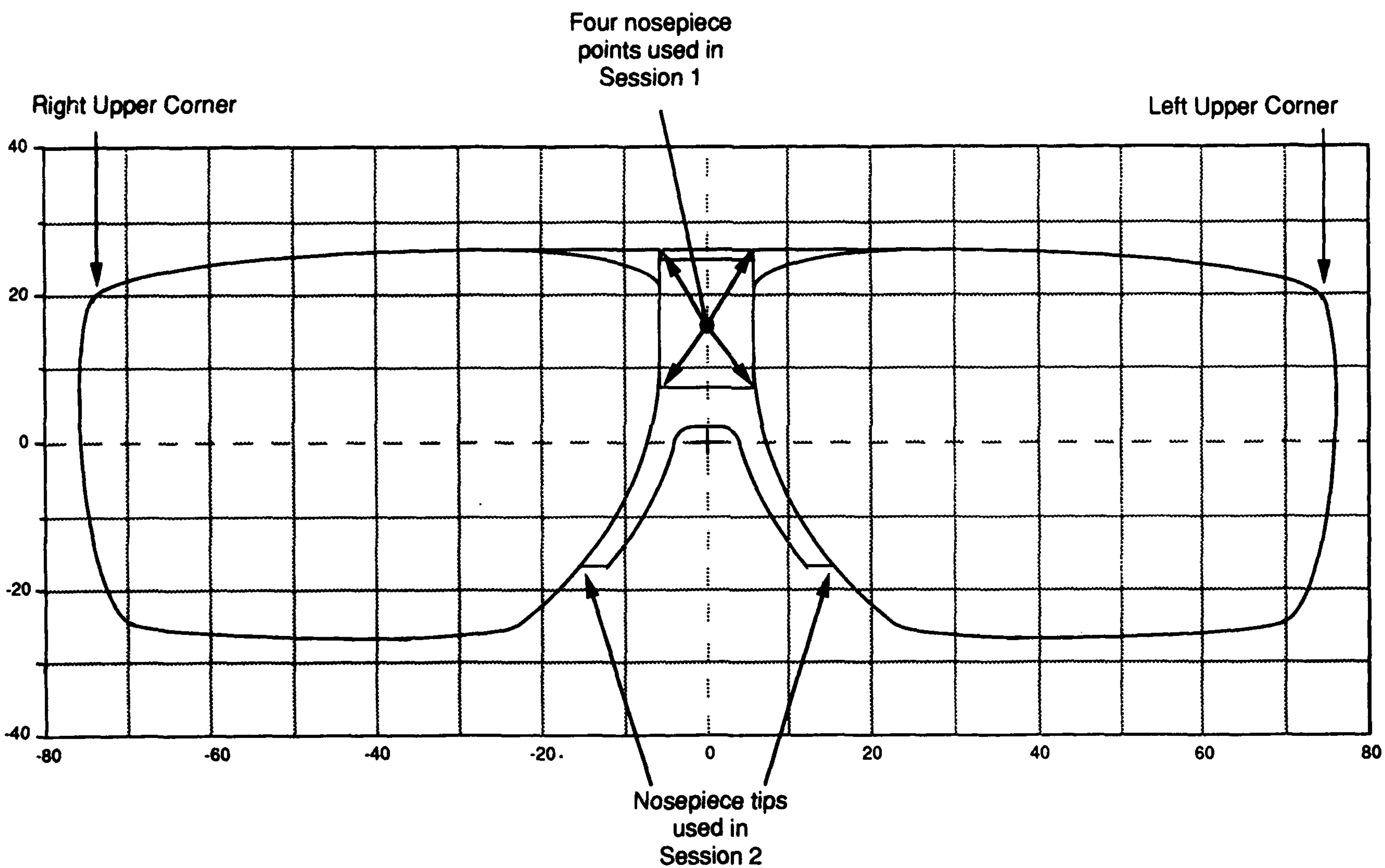


Figure 2. Landmarks on the B-LPS Used in Lateral View Analyses

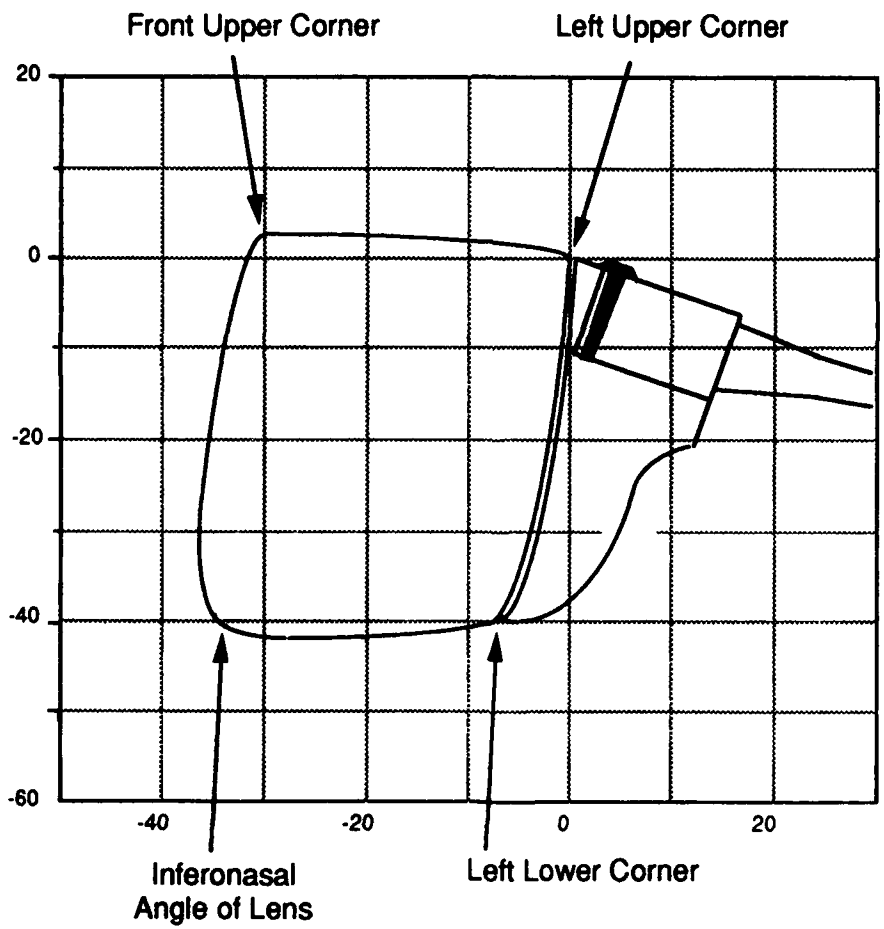


Figure 3.

LOSLIP Y-coordinate Estimation:
Comparison of Method 1 versus Method 2

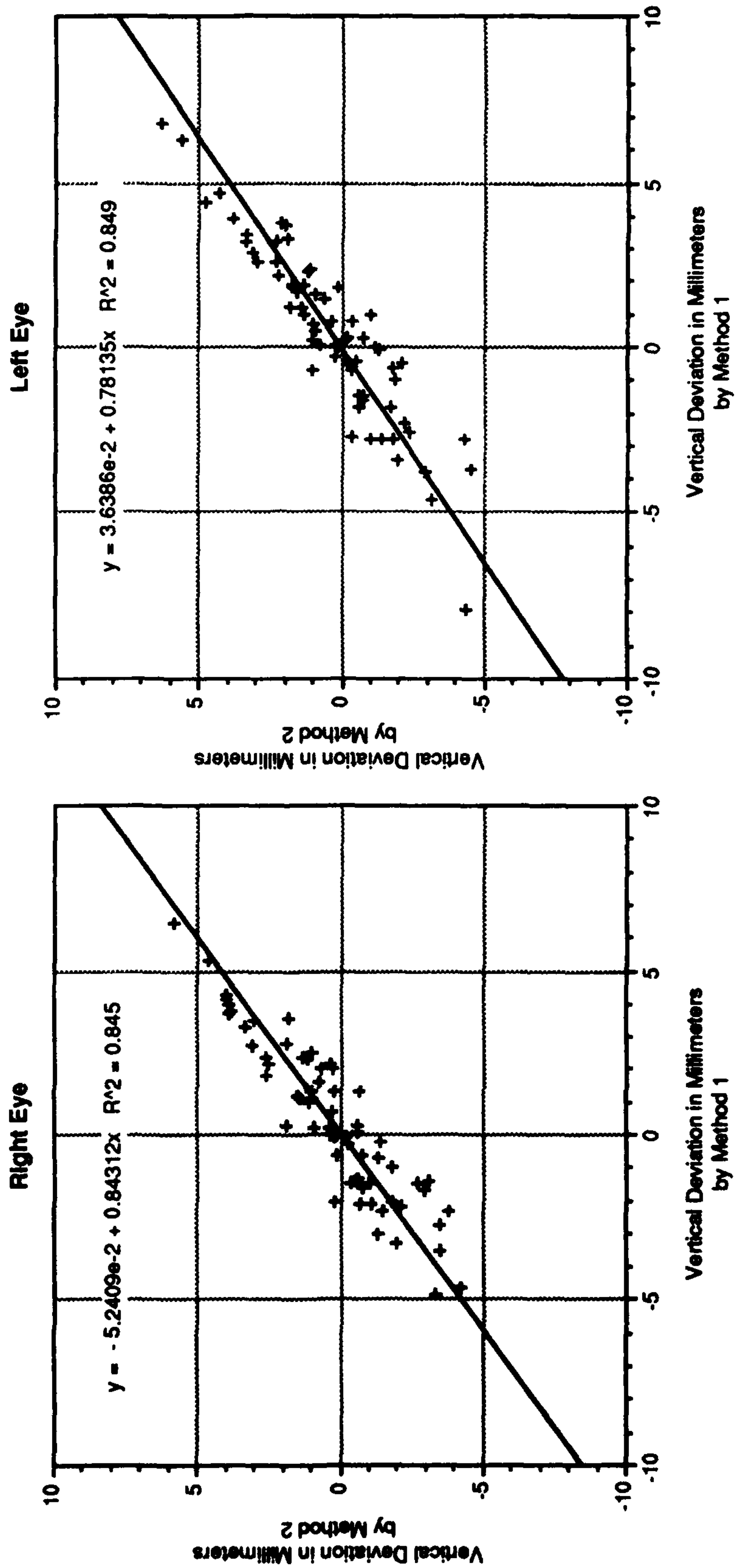
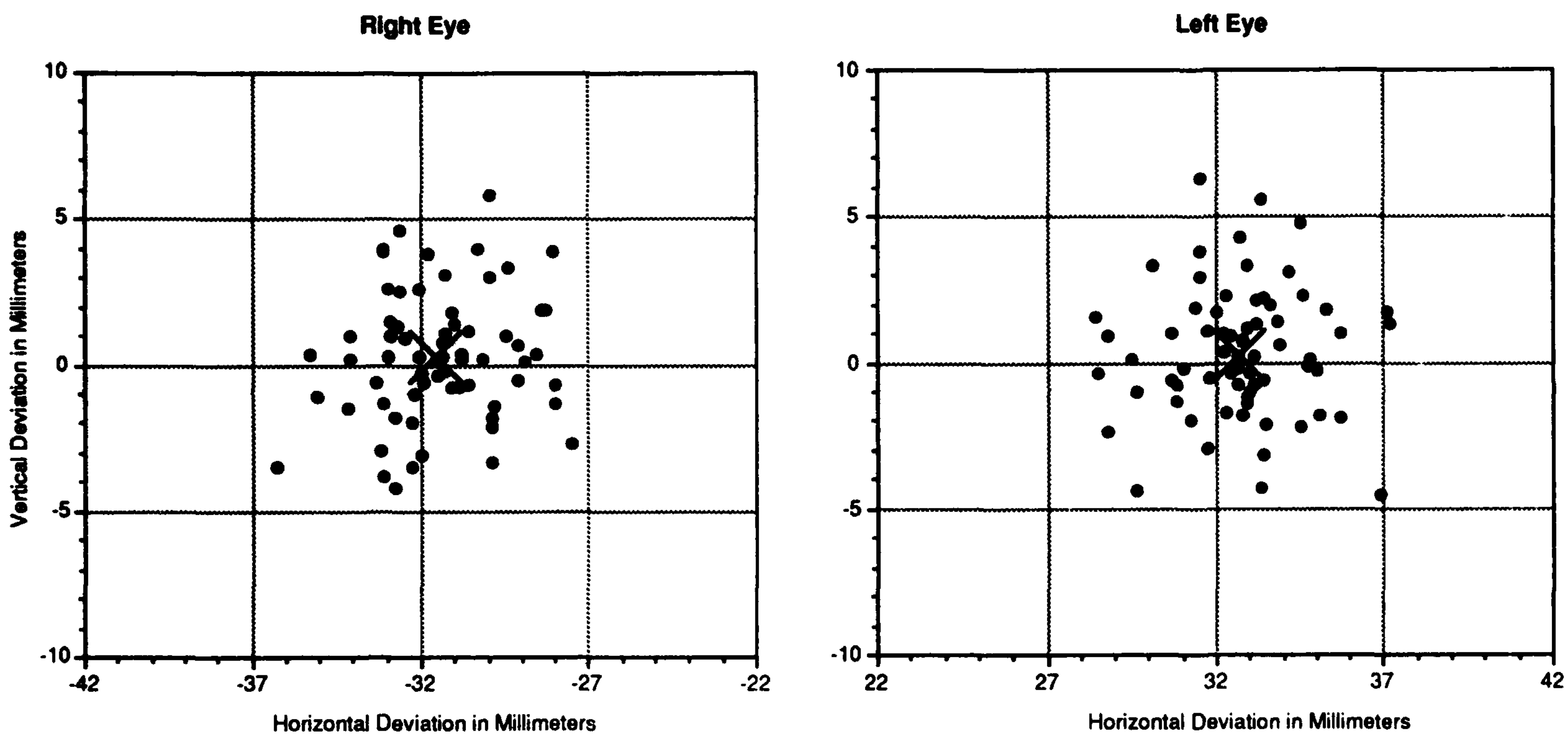


Figure 4. **Pupil Locations in the Frontal Plane**



Right Eye:

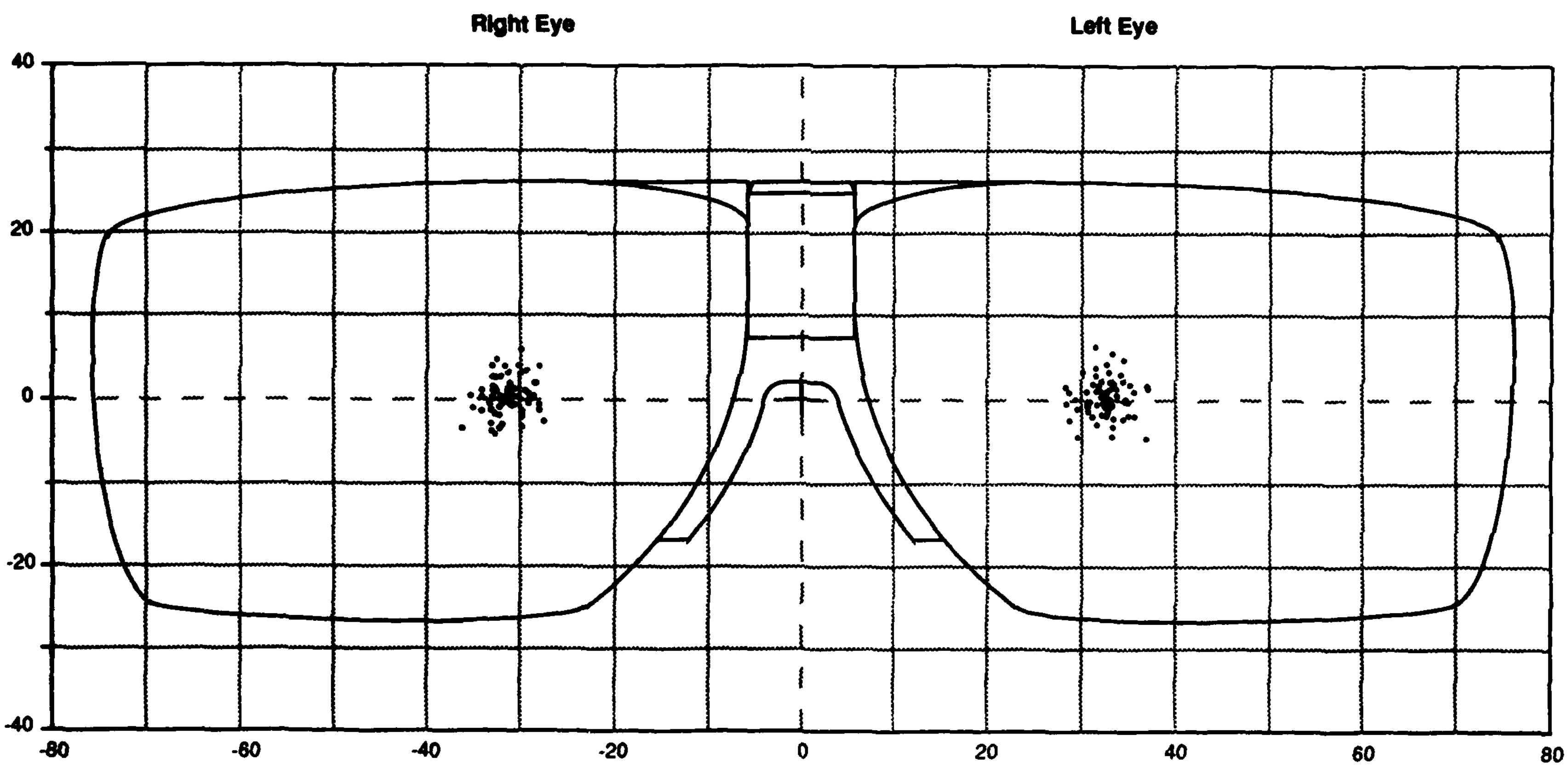
Center Location: (-31.5, 0.3)
50% radius: 2.5 mm
75% radius: 3.6 mm
95% radius: 4.9 mm

Left Eye:

Center Location: (32.7, 0.3)
50% radius: 2.2 mm
75% radius: 3.6 mm
95% radius: 5.3 mm

Figure 5.

Line-of-Sight/Lens Intersection Point (LOSLIP)
for 67 Soldiers
as seen in the Frontal Plane



Center Location:	(-31.5, 0.3)	Center Location:	(32.7, 0.3)
50% radius:	2.5 mm	50% radius:	2.2 mm
75% radius:	3.6 mm	75% radius:	3.6 mm
95% radius:	4.9 mm	95% radius:	5.3 mm

Figure 6.

Distance between the left LOSLIP and COE in Millimeters: Comparison of Two Methods

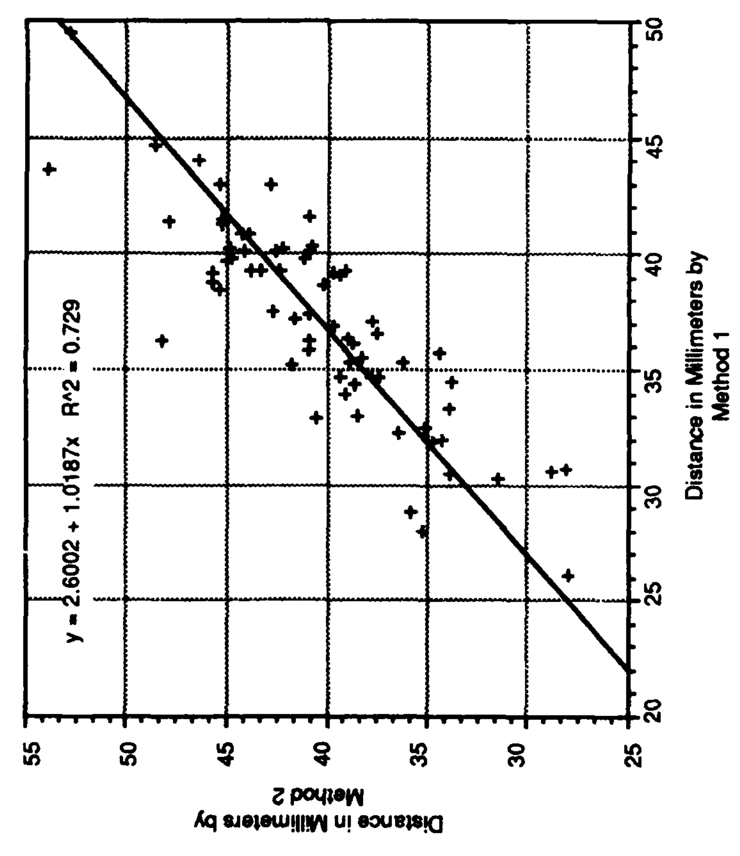


Figure 7. **Left LOSLIP-COE distance (Z by Method 2) versus the Left COE X- and Y-axis Locations**

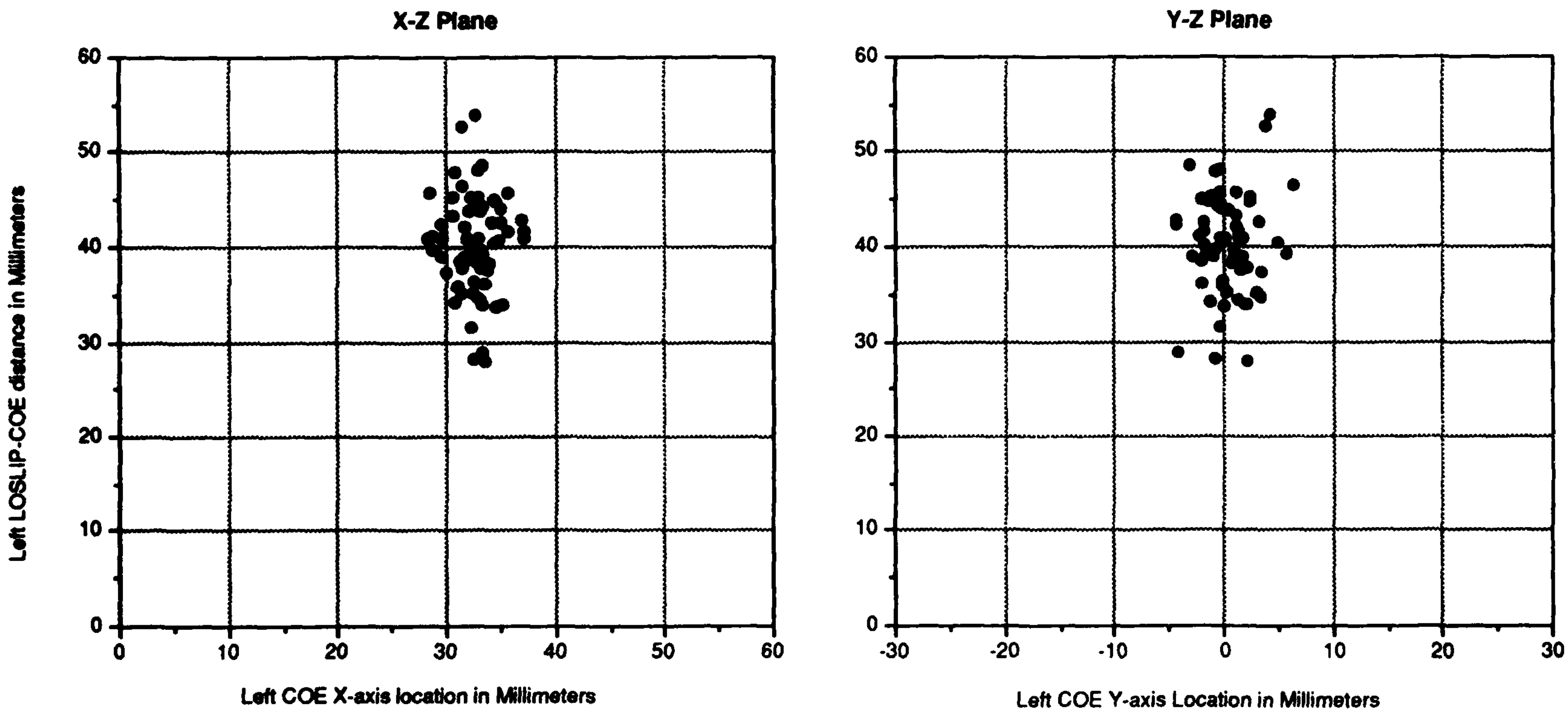
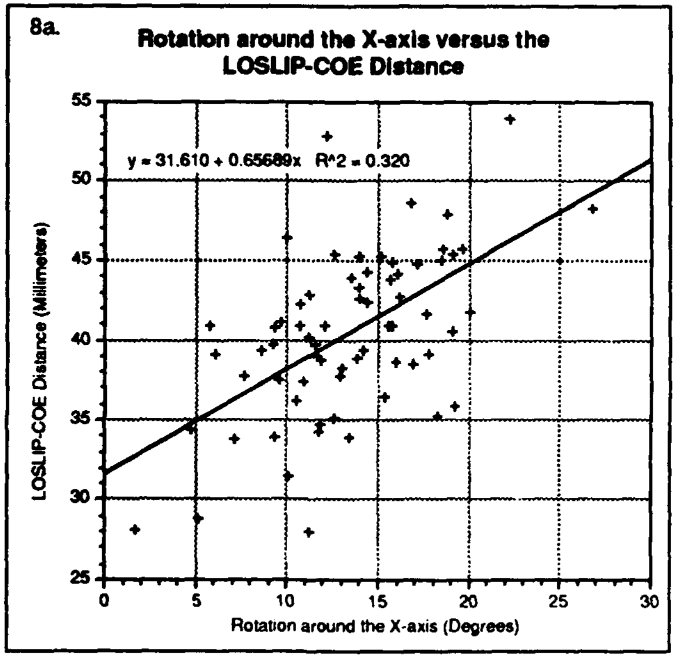


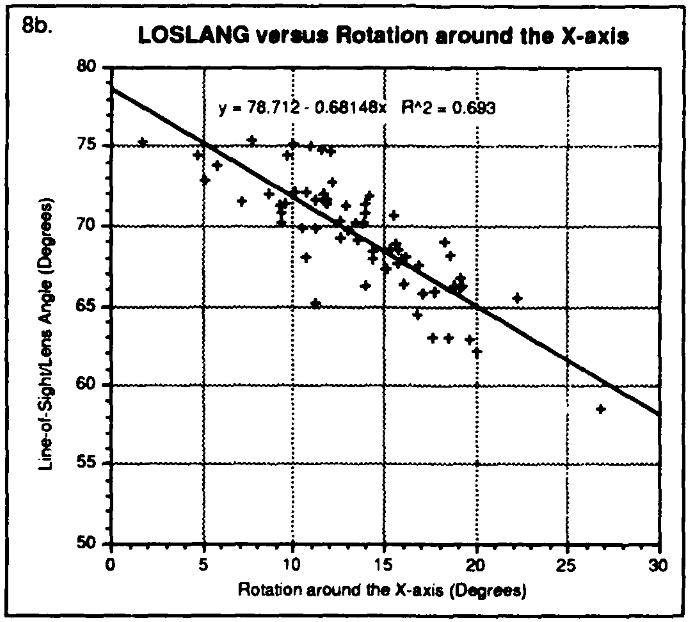
Figure 8.

Relationships Between the LOSLANG, the LOSLIP-COE Distance, and Rotation around theX-axis

8a.



8b.



8c.

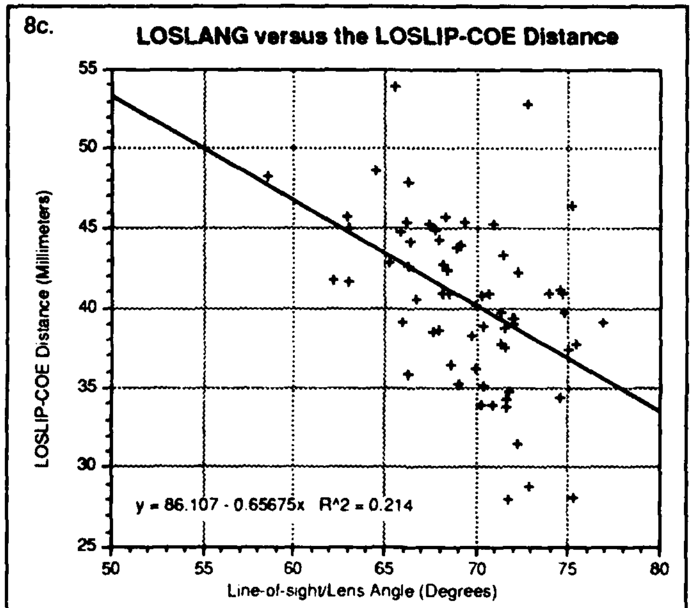


Table I. Estimated Anthropometric Parameters	
LOSLIP x-coordinate (Right and Left)	Distance along the x-axis of the point defined by the intersection of the line-of-sight and the anterior surface of the B-LPS lens (LOSLIP = Line-of-sight/Lens Intersection Point)
LOSLIP y-coordinate (Right and Left)	Distance along the y-axis of the point defined by the intersection of the line-of-sight and the anterior surface of the B-LPS lens (LOSLIP = Line-of-sight/Lens Intersection Point)
LOSLIP-COE distance (Left only)	Distance between the LOSLIP and the rotational center of the eye (COE)
Z-axis Rotation	Rotation of the B-LPS around the Z-axis (seen in frontal view photograph)
X-axis Rotation	Rotation of the B-LPS around the Z-axis (seen in frontal view photograph)
LOSLANG	Angle formed by the intersection of the line-of-sight with the plane tangent to the anterior surface of the B-LPS lens at the point where the line-of-sight passes through the lens (LOSLANG = Line-of-sight/Lens Angle)

Table II. Examples of Intra-Rater Variability Associated with the Measurement of Selected Coordinates on the Frontal Photograph. Shown are the mean and standard deviation (in millimeters) for each repetition of each rater for each of four coordinates. For rater 1, for example, the mean of the x-coordinate for point 2 across all subjects during the first time through the photographs was 45.61. The mean estimates are of distances on the photograph (i.e., non-scaled to real-world B-LPS). The Pearson product-moment correlation coefficients represent the correlation between the first and second repetitions for each rater.

		Rater 1		Rater 2		Rater 3		Rater 4	
Coord	Rep	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2x	1	45.61	1.49	45.67	1.55	45.54	1.57	45.73	1.66
	2	45.86	1.53	45.46	1.50	45.20	1.49	45.60	1.54
		r = .9809		r = .9654		r = .9794		r = .9605	
3y	1	-4.42	0.69	-4.30	0.67	-4.32	0.67	-4.33	0.68
	2	-4.42	0.65	-4.19	0.62	-4.43	0.72	-4.41	0.66
		r = .9339		r = .8370		r = .8669		r = .8727	
7x	1	32.62	1.32	32.67	1.34	32.75	1.33	32.82	1.29
	2	32.82	1.34	32.50	1.31	32.54	1.31	32.67	1.30
		r = .9808		r = .9749		r = .9652		r = .9662	
7y	1	-6.76	0.86	-6.65	0.83	-6.83	0.80	-6.62	0.87
	2	-6.74	0.85	-6.60	0.84	-6.86	0.83	-6.62	0.89
		r = .9678		r = .9428		r = .9623		r = .9464	

Table III. Examples of Inter-Rater Variability Associated with the Measurement of Selected Coordinates on the Frontal Photograph. Shown are the Pearson product-moment correlation coefficients comparing raters for each of four coordinates.

Point 2x		Rater 1	2	3	4
Rater	1	1.000	.9831	.9813	.9806
	2		1.000	.9790	.9750
	3			1.000	.9750
	4				1.000

Point 3y		Rater 1	2	3	4
Rater	1	1.000	9392	.9151	.9431
	2		1.000	.9338	.9034
	3			1.000	.9031
	4				1.000

Point 7x		Rater 1	2	3	4
Rater	1	1.000	.9769	.9812	.9811
	2		1.000	.9806	.9803
	3			1.000	.9777
	4				1.000

Point 7y		Rater 1	2	3	4
Rater	1	1.000	.9737	.9766	.9738
	2		1.000	.9611	.9649
	3			1.000	.9770
	4				1.000

Table IV. Summary Statistics of Parameters Associated with the Positional Variability of the B-LPS.

Parameter	Design Value	Mean	SEM	SD	Min.	Max	Range
Right LOSLIP x (mm)	-32.0	-31.5	0.26	2.10	-39.7	-29.6	10.1
Left LOSLIP x (mm)	32.0	32.7	0.27	2.17	31.2	41.0	9.8
Right LOSLIP y (mm)	0	0.28	0.27	2.21	-4.2	5.8	10.0
Left LOSLIP y (mm)	0	0.35	0.27	2.24	-4.5	6.3	10.8
Left LOSLIP- COE distance (mm)	32.25*	40.4	0.63	5.12	28.1	54.0	25.9
Rotation Around:							
Z-axis (deg)	0	0.05	0.14	1.13	-3.4	2.5	5.9
X-axis (deg)	0	13.4	0.55	4.47	1.7	26.7	25.0
LOSLANG (deg)	80	69.6	0.45	3.66	58.5	76.9	18.4

X - x-coordinate of the point
Y - y-coordinate of the point
LOSLIP - Line-of-Sight/Lens Intersection Point (located at the front surface of the lens)
COE - Center of the Eye (rotational center)
LOSLANG - Line-of-Sight/Lens Angle (angle formed by the line-of-sight and the plane tangent to the front surface of the B-LPS at the LOSLIP)

* Design LOSLIP-COE distance = COE to anterior aspect of cornea (13.25mm) + anterior aspect of cornea to Ballistic Protective Eyewrap (17mm) + thickness of eyewrap (2 mm)

Table V. Mean Summary Statistics for Select Subgroups.

	Sample Size	Right LOSLIP x-coordinate (mm)	Left LOSLIP x-coordinate (mm)	Right LOSLIP y-coordinate (mm)	Left LOSLIP y-coordinate (mm)	Left LOSLIP-COE distance (mm)	Rotation around the Z-axis (degrees)	Rotation around the X-axis (degrees)	Left LOSLANG (degrees)
Officers	18	-31.7	33.2	0.2	0.5	39.6	0.4	11.0	70.7
Enlisted	49	-31.3	32.5	0.3	0.3	40.7	-0.1	14.3	69.2
User: Heavy	28	-31.4	32.7	0.0	0.3	40.4	0.3	12.5	70.0
Light	39	-31.5	32.7	0.5	0.4	40.4	-0.1	14.0	69.3
Wears Glasses: Yes	28	-31.5	32.3	0.4	0.3	41.1	-0.1	13.0	70.1
No	39	-31.5	32.9	0.2	0.4	39.9	0.2	13.7	69.2
Nose Pads: Yes	27	-31.5	32.8	0.1	0.3	41.9	0.2	13.7	69.1
No	33	-31.5	32.7	0.4	0.4	38.6	0.0	12.4	70.5
No response	7	-31.4	32.6	0.6	0.3	43.5	-0.4	17.0	67.1
Restraining Band: Uses	47	-31.5	32.8	0.2	0.3	40.6	0.1	13.1	69.7
Doesn't Use	8	-31.5	32.7	0.4	0.5	37.9	0.0	12.4	70.2
No response	12	-31.4	32.1	0.6	0.4	43.0	-0.3	16.3	68.1
Helmet Problems: Yes	33	-31.4	32.9	0.7	0.6	39.6	-0.2	12.8	70.0
No	30	-31.6	32.3	-0.2	0.0	41.0	0.3	13.7	69.5
No response	4	-31.4	33.5	0.5	0.7	42.7	0.3	16.4	67.1
Average	67	-31.5	32.7	0.28	0.35	40.4	0.05	13.4	69.6

X - x-coordinate of the point
Y - y-coordinate of the point
LOSLIP - Line-of-Sight/Lens Intersection Point (located at the front surface of the lens)
COE - Center of the Eye (rotational center)
LOSLANG - Line-of-Sight/Lens Angle (angle formed by the line-of-sight and the plane tangent to the front surface of the B-LPS at the LOSLIP)

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